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ABSTRACT

The main objective of the study reported in this paper was to construct a Lakatosian teaching strategy that can facilitate conceptual change in students' understanding of chemical equilibrium. The strategy is based on the premise that cognitive conflicts must have been engendered by the students themselves in trying to cope with different problem solving strategies. Results obtained (based on Venezuelan freshman students) show that the performance of the experimental group of students was generally better (especially on the immediate posttests) than that of the control group It was concluded that a conceptual change teaching strategy must take into consideration the following aspects: core beliefs of the students in the topic; exploration of the relationship between core beliefs and student alternative conceptions; cognitive complexity of the core belief can be broken down into a series of related probing questions; students resist changes in their core beliefs by postulating auxiliary hypotheses in order to resolve their contradictions; students' responses based on their alternative conceptions must not be considered wrong, but rather as models; and students' misconceptions should be considered as alternative conceptions that compete witl. the present scientific theories and at times recapitulate theories scientists held in the past. Contains 53 references. (Author/JRH)

A LAKATOSIAN CONCEPTUAL CHANGE TEACHING STRATEGY BASED ON STUDENT ABILITY TO BUILD MODELS WITH VARYING DEGREES OF CONCEPTUAL UNDERSTANDING OF CHEMICAL EQUILIBRIUM

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ABSTRACT

The main objective of this study is to construct a Lakatosian teaching strategy that can facilitate conceptual change in students' understanding of chemical equilibrium. The strategy is based on the premise that cognitive conflicts must have been engendered by the students themselves in trying to cope with different problem solving strategies. Results obtained (based on Venezuelan freshman students) show that the performance of the experimental group of students was generally better (especially on the immediate posttests) than that of the control group. It is concluded that a conceptual change teaching strategy must take into consideration the following aspects: a) core beliefs of the students in the topic (cf. 'hard core', Lakatos, 1970); b) exploration of the relationship between core beliefs and student alternative conceptions (misconceptions); c) cognitive complexity of the core belief can be broken down into a series of related and probing questions; d) students resist changes in their core beliefs by postulating 'auxiliary hypotheses' in order to resolve their contradictions; e) students' responses based on their alternative conceptions must be considered not as wrong, but rather as models, perhaps in the same sense as used by scientists to break the complexity of a problem; and f) students' misconceptions be considered as alternative conceptions (theories) that compete with the present scientific theories and at times recapitulate theories scientists held in the past.

A LAKATOSIAN FRAMEWORK FOR CONCEPTUAL CHANGE TEACHING

Chemical equilibrium is considered to be one of the most difficult topics in the general chemistry program (Stewart, Finley & Yarroch, 1982). Various studies have investigated student difficulties in the topic (Banerjee, 1991; Bannerjee & Power, 1991; Camacho & Good, 1989; Gussarsky & Gorodetsky, 1988; Hackling & Garnett, 1985; Hameed, Hackling & Garnett, 1993; Johnstone, MacDonald & Webb, 1977; Maskill & Cachapuz, 1989; Niaz, 1995b; Wheeler & Kass, 1978).

According to Hackling and Garnett (1985) one of the most significant alternative conception (misconception) students hold is that, "The rate of the forward reaction increases with time from the mixing of the reactants until equilibrium is established" (p. 213). In a recent study Niaz (1995b) found that those students who understood that the (see Item 1 in Method's section) "... rate of the forward reaction decreases as the reaction gets going ..., subsequently perform extremely well on other related aspects of chemical equilibrium" (p.). For example, it was found that in spite of the misconceptions with respect to the rate of the forward reaction (only 22% of the students responded correctly on Item 1a): 1) 49% of the students do understand that to begin with the rate of the reverse reaction is zero and increases progressively as the concentration of the products increases (cf. Items 1b and 1c); 2) 62% of the students understand that the rates of the forward and reverse reactions are equal only at equilibrium; 3) of the students who correctly (22%) predicted that the rate of the forward reaction decreases, 88% understood that the rate of the reverse reaction increases as the concentration of the products increases, 94% understood that in the beginning the rate of the reverse reaction is zero, and 100% understood that the rates of forward and reverse reactions are equal only at equilibrium. Similar results were obtained in other items (cf. Niaz, 1995b). Furthermore, support was found for the hypothesis that students who perform better on problems requiring conceptual understanding also perform significantly better on computationl problems requiring algorithms.

These results indicate that student conceptualization of the rate of the forward reaction is more resilient to instruction in the traditional classroom, and thus can be considered as a major theoretical framework (core belief) of student misconceptions. On the other hand, students who responded correctly to Item 1a, performed extremely well on Items 1b, 1c, and 1d (see Item 1 Method's section). It is plausible to suggest that student misconception of the rate of forward reaction represents the hard core (negative heuristic) of their framework in the Lakatosian (Lakatos, 1970) sense. Again, according to the Lakatosian framework student understanding of Items 1b, 1c, and 1d would represent the soft core (positive heuristic) of their framework, which offers relatively less resistance to conceptual change. Chinn and Brewer (1993), taking their cue from Lakatos have emphasized that students resist changes in their major theoretical frameworks (e.g., Item 1a), by accepting 'auxiliary hypotheses'. Niaz (1995b) found that many students who held the misconception regarding the rate of the forward reaction (Item 1a) reasoned by postulating an 'auxiliary hypothesis': "As the reaction has to reach equilibrium its forward rate must increase" (p.   ). Duschl and Gitomer (1991) have referred to changes in the major frameworks of the students as 'strong restructuring' (p. 842) similar to Kuhn's 'revolutionary science' and Lakatos's abandonment of a research program's hard core (negative heuristic). Similarly, 'weak restructuring' would correspond to Kuhn's idea of alterations during 'normal science' and Lakatos's idea of changes in the soft core of a research program. In the present context student understanding of Item 1a would require 'strong restructuring' and Items 1b, 1c, and 1d would require 'weak restructuring'. Given the parallel between the process of theory development by scientists and an individual's acquisition of knowledge (cf. Duschl & Gitomer, 1991; Kitchener, 1987; Piaget & Garcia, 1989; von Glasersfeld, 1989), it is not surprising that students resist changes in their major theoretical frameworks. According to Lakatos (1970), scientists do not abandon a theory on the basis of contradictory evidence alone and, "There is no falsification before the emergence of a better theory" (p. 119). As an illustration Niaz (1991, 1993c, 1995a) has drawn a parallel between the methodology of idealization (simplifying assumptions) used by scientists and the construction of strategies (models) by students to facilitate conceptual understanding. In this respect it is particularly instructive to consider the Lakatosian rational reconstruction of Bohr's and Newton's research programs (cf. Lakatos, 1970, p. 146 and pp. 135-136).

At this stage it is essential to point out that in spite of the similarities, Kuhnian and Lakatosian conceptualizations of the progress of science are fundamentally different. For Kuhn (1970) scientific progress is based on the displacement of one paradigm by another, through a process of chaotic upheaval or scientific revolution. Furthermore, different paradigms are incommensurate, viz., core beliefs of scientists do not permit rational debate among different research programs. On the other hand, Lakatos (1970) presents a very different picture: "[Kuhnian] 'normal science' is nothing but a research programme that has achieved monopoly. But as a matter of fact, research programmes have achieved complete monopoly only rarely and then only for relatively short periods ... The history of science has been and should be a history of competing research programmes (or, if you wish, 'paradigms'), but it has not been and must not become a succession of periods of normal science ..." (p. 155). These two opposing views of the progress of science have important implications for science education (see last section for details).

Lakatos' philosophy of science has been applied previously to interpret research in science education (cf. Gilbert & Swift, 1985; Linn & Songer, 1991; Niaz, 1993a, 1993b, 1994). More recently, Niaz (1995a) has shown that student performance on algorithmic and conceptual chemistry problems can be interpreted as a process of progressive transitions (models) that facilitate different degrees of explanatory / heuristic power to student conceptual understanding, similar to what Lakatos (1970) has referred to as the rational reconstruction of scientific research programs.

Criteria for classification of students' responses as part of a Lakatosian core belief

1. Deletion criterion. Faced with a similar problem in Piagetian theory, Beilin (1985) has proposed a 'deletion criterion': "If a construct in the theory can be deleted without apparent damage to the identification of the theory as Piaget's, then it is not part of the hard core. If on the other hand, deletion detracts materially from the theory or alters it in irreparable ways, then it is a part of the hard core" (pp. 109-110).
2. Hard core and protective belt propositions. According to Chinn and Brewer (1993): "Lakatos (1970) has distinguised between two types of propositions within a theory: hard core propositions and protective belt [soft core] propositions. Hard core propsitions cannot be altered without scrapping the entire theory, but protective belt propositions can be altered while preserving the key central hypotheses" (p. 10, original italics).
3. Auxiliary hypotheses. Given the opportunity for conceptual change, students invariably tend to accept changes in their frameworks (soft core) but resist changes to the hard core by offering 'auxiliary hypotheses'. In the history of science Lakatos (1970, p. 153), for example, considers Pauli's

'exclusion principle' as an 'auxiliary hypothesis', that protected the hard core of Bohr's theory.

Let us now try to understand the classification of Items 1a, 1b, 1c, and 1d (see Method's section) according to the criteria presented above. As suggested previously, Item 1a can be considered as a 'core belief' of student understanding, whereas Items 1b, 1c, and 1d would represent the dispensable part (soft core / positive heuristic). Results obtained in a previous study (Niaz, 1995b) with similar students have shown that most of those who responded correctly to Item 1a also responded correctly to Items 1b, 1c, and 1d. Furthermore, many Ss who responded incorrectly to Item 1a, reasoned by postulating an 'auxiliary hypothesis': "As the reaction has to reach equilibrium its forward rate must increase" (p.). A careful look at Items 1b, 1c, and 1d would show them to be partial constituents of Item 1a, viz., a correct understanding of Item 1a, forward reaction rate decreases with time, leads to the following conceptualizations:

--- reverse reaction rate increases because the forward reaction rate provides the product (Item 1b).

--- when the reaction has just started and the product is absent, the reverse reaction rate is zero (Item 1c).

--- as the reaction progresses, the forward and reverse reaction rates would be equal only in the state of equilibrium (Item 1d).

This shows quite clearly how Item 1a affects understanding of Items

1b, 1c, and 1d. Deletion of Items 1b / 1c / 1d would perhaps partially affect understanding on Item 1a. However, deletion of Item 1a would perhaps lead to a 'scrapping' of the entire framework of students' understanding. Deletion in this context would amount to solving this problem without the understanding provided by Item 1a, viz., forward reaction rate decreases with time.

Summarizing: Application of Beilin's 'deletion criterion' (criterion 1) shows that deletion of student understanding of Item 1a (core belief) would lead to a 'scrapping' of the entire framework of student understanding (criterion 2) and hence they use 'auxiliary hypotheses' precisely to protect their core belief (criterion 3).

PURPOSE

The main objective of this study is to construct a teaching strategy that could facilitate conceptual change in students' understanding of chemical equilibrium. The teaching strategy is based on the following fundamental assumptions:

1. By emphasizing certain key aspects of chemical equilibrium (cf. Lakatos's, 1970, hard core) we may start a 'chain reaction' that may facilitate conceptual understanding.
2. After being exposed to closely related, alternative probing questions students may give up a certain mode of thinking, at least partially. This was observed in a previous study (Niaz, 1995b) based on student understanding of chemical equilibrium.

According to Duschl and Gitomer (1991): "Careful evaluation of student knowledge claims can help teachers design instructional experiences that will force a grappling with those beliefs, and thereby encourage conceptual restructuring" (p. 840).

3. As a pre-requiste for conceptual change it is essential that students be provided with alternative views that apparently contradict their previous thinking. This is based on the Lakatosian thesis that the, "... history of science has been and should be a history of competing research programmes (or, if you wish 'paradigms') but it has not been and must not become a succession of periods of normal science ..." (Lakatos, 1970, p. 155).

4. The new / alternative framework must appear initially plausible to the students (cf. Strike & Posner, 1985).

5. Based on Lakatosian methodology it is suggested that: "... the individual can add or abandon auxiliary theoretical hypotheses, change beliefs about how experiments in the theoretical domain should be conducted, adjust the definition of a theoretical construct, or alter the domain of the theory. In all of these cases, however, the changes leave the theory's central hypotheses intact" (Chinn & Brewer, 1993, p. 11).

6. Cognitive conflicts must have been engendered by the students themselves in trying to cope with different problem solving strategies. According to Mischel (1971): "The cognitive conflicts which the child himself engenders in trying to cope

with his world, are then what motivates his cognitive development; they are his motives for reconstructing his system of cognitive schemas ..." (p. 332).

7. Teaching strategy developed in this study is based on an interactive approach within an intact classroom. According to Rowell and Dawson (1985) most of the researchers have worked with individuals or very small groups, thus ignoring the importance of, "... classroom practice which is premised on teaching classes as units" (p. 331).

A major hypothesis of this study is that students' participation in the teaching experiments (strategies) facilitates their conceptual understanding of chemical equilibrium.

METHOD

This study is based on two intact sections of freshman students (Ss) who had registered for Chemistry II at the Universidad de Oriente, Venezuela. One of the sections (N = 32) was randomly designated as the control group and the other section (N = 36) as the experimental group. Ss assignment to a section is not based on any particular variable related to their academic / cognitive ability. Furthermore, author's previous experience shows that students in different sections perform at about the same level. Both sections were taught by the author. Mean age of the students in the control and experimental groups was 18.9 years (SD

= 1.2) and 19.1 years (SD = 1.3), respectively. All Ss had one or more of the following textbooks: Mahan (19 8); Mahan and Myers (1990); Masterton, Slowinski, and Stanitski (1985); and Whitten, Gailey and Davis (1992). Besides the textbooks Ss were given handouts with problems quite similar to Posttests 3 and 4.

Teaching Experiments

In order to implement the teaching strategy the experimental group was exposed to two 'teaching experiments' based on the fundamental assumptions mentioned in the previous section and adapted from Cobb and Steffe (1983). According to D'Ambrosio and Campos (1992): "The instructor's role in the 'teaching experiment' is to generate questions or changes in the learner's experiential field that lead the learners into situations in which they experience conflicts or contradictions between their representations and those needed to interpret those situations" (p. 215). The two experiments were conducted during the fourth and fifth week of the semester and dealt with the topic of chemical equilibrium. Besides the two problems included in the two teaching experiments, both the experimental and control groups solved the same set of 8 other problems of chemical equilibrium. In order to compensate for the two teaching experiments, the control group solved two similar problems with a traditional format. Both the control and the experimental groups used an interactive participatory approach to problem solving. In both groups the Ss were encouraged to discuss the problems, express their opinions and often called to the chalkboard to solve problems. Except for the two teaching experiments, every effort was made to provide similar experiences to the two groups. It is important to note that Ss in both groups had very similar opportunities to ask questions, propose solutions, generate discussions and encouraged to use the chalkboard to express their points of view.

<u>Teaching Experiment 1</u>

During the fourth week of the semester Ss in the experimental group were presented the following problem:

> A certain amount of $NO(g)$ and $Cl_2(g)$ are introduced in a vessel, whose temperature is maintained constant. After the reaction has started and before the equilibrium is reached, it can be concluded that:
>
> $$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad (\Delta H < 0)$$
>
> <u>Item 1a</u>: Forward reaction rate increases as the reaction gets going.
>
> <u>Item 1b</u>: Reverse reaction rate increases as the concentration of the products increases.
>
> <u>Item 1c</u>: In the beginning the reverse reaction rate is zero.
>
> <u>Item 1d</u>: Reverse reaction rate is the same as the forward reaction rate.

This item was adapted with some changes from Hackling and Garnett (1985), and formed part of the study by Niaz (1995b) discussed previously. Ss were first given about 10 minutes to read the problem and familiarize with the problem situation. One of the Ss then was asked to read the problem loud to the rest of the class. Another student was asked to suggest a solution to Item 1a. In an attempt to provide a conflicting situation Ss were asked to consider the consequences of the statement in Item 1a, whether correct or incorrect. Students were asked to consider the following possibilities: a) As the reaction gets going, concentration of the reactants would decrease. How would that effect the rate of the forward reaction?; b) If the forward reaction rate increases, would that mean more of the reactants are available. Ss were encouraged to express their opinions and discuss with their neighbors. After some discussion some of the Ss grasped the contradiction between the two possibilities mentioned earlier. When the correct response sort of emerged from the discussion it was quite clear that not all Ss were equally convinced. Items 1b, 1c, and 1d were dealt with in a similar manner. The whole experiment lasted about 40 minutes. Some of the salient points regarding the teaching experiment were: a) Ss were sort of surprised to be solving a problem that involved so much reasoning and discussion; b) The fact that no quantiative calculations were required, was another novel feature for the Ss; c) Item 1a was clearly the most difficult for the Ss; and d) Some of the Ss were clearly not satisfied with various aspects of the discussion and the correct responses.

Teaching Experiment 2

During the fifth week of the semester, Ss in the experimental group were presented the following problem:

A certain amount of $NO(g)$ and $Cl_2(g)$ are introduced in a vessel at a certain temperature:

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad (\Delta H < 0)$$

After the equilibrium is reached the temperature is increased and as a consequence it can be concluded that:

Item 2a: Forward reaction rate decreases.

Item 2b: Reverse reaction rate increases.

Item 2c: Forward reaction rate increases gradually.

Item 2d: When the equilibrium is re-established, the equilibrium constant remains the same.

Item 2e: Reverse reaction rate would be greater than the forward reaction rate.

Item 2f: When the equilibrium is re-established the equilibrium constant decreases.

This problem was adapted with some changes from Hackling and Garnett (1985) and formed part of the study by Niaz (1995b) discussed previously. Procedure for presentation and discussion by the Ss was the same as in Teaching Experiment 1. Total time required for the experiment was about 45 minutes.

Evaluation of the teaching experiments

In order to evaluate the effectiveness of the teaching experiments, both the experimental and the control groups were tested on five different problems at different intervals of time, referred to as posttests, according to the following schedule: Posttests 1, 2 and 3 (8 week, monthly exam); Posttests 4 and 5 (13 week, semester exam). All 5 posttests formed part of the regular evaluation of the Ss. Posttest 1 was adapted with some changes from Hackling and Garnett (1985). Posttest 2 was adapted from Mahan (1968). Posttests 3 and 4 were adapted from Masterton, Slowinski and Stanitski (1985). Posttest 5 was adapted from Niaz (1994b). Posttests 1, 2 and 3 also formed part of the study by Niaz (1994a), and were designed as immediate posttests. Posttests 4 and 5 were considered to be delayed posttests. Posttest 1 was quite similar to the problems used in the two teaching experiments. The other posttests were different and designed to evaluate transfer of problem solving strategies. Students were encouraged to explain and justify all responses. Posttests 2, 3 and 4 are generally found in textbooks. On the other hand, formats of posttests 1 and 5 are fairly novel (based on statements rather than formal questions, with no calculations) requiring greater conceptual understanding and effort on the part of the Ss. A major objective of this format is that we wanted the Ss to interpret the underlying concept in their own words and not just use calculations based on memorized rules and formulae. Recent literature in chemistry education has been particularly critical of the algorithmic (plug-and-chug) approach to freshman chemistry (cf. De Berg, 1989; Nurrenbern & Pickering, 1987; Sawrey, 1990; Nakhleh, 1993; Nakhleh & Mitchell, 1993; Niaz, 1995a; Niaz & Robinson, 1993). Before starting to respond the posttests Ss were specifically asked to: a) read the items carefully; and b) note that except for Posttest 5, these were not multiple-choice items and hence they were supposed to respond to all parts of an item and justify every part in order to get full credit. Students at this university are fairly accustomed to justifyijng their responses in writing and exams are not corrected by the computer. Even on Posttest 5 they were asked to justify the selected response.

Posttest 1 (8 week)

A certain amount of $NO(g)$ and $Cl_2(g)$ are introduced in a vessel and the temperature is maintained constant. After the equilibrium is reached a certain amount of $NO(g)$ is introduced into the vessel. As a consequence it can be concluded that:

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCL(g) \quad (\Delta H < 0)$$

Item a: Reverse reaction rate decreases.

Item b: Forward reaction rate increases instantaneously.

Item c: Initially the reverse reaction rate remains constant.

Item d: Reverse reaction rate increases gradually.

Posttest 2 (8 week)

Nitrosyl bromide decomposes according to the following reaction: $NOBr(g) \rightleftharpoons NO(g) + 1/2Br_2(g)$

At 77° C, K_p of the reaction is 0.15. If 0.50 atm of $NOBr(g)$, 0.20 atm of $NO(g)$, and 0.40 atm of $Br_2(g)$ are introduced in a vessel at 77° C, it can be concluded that in the state of equilibrium:

Item a: P_{NO} is greater than 0.20 atm.

Item b: P_{Br} is greater than 0.40 atm.

Item c: P_{NOBr} is less than 0.50 atm.

Item d: P_{Br} is less than 0.30 atm.

Item e: P_{NOBr} is greater than 0.70 atm.

Posttest 3 (8 week)

Consider the following reaction in equilibrium:

$$2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g) \quad (\Delta H > 0)$$

Describe the effect of the following on the position of the equilibrium:

Item a: Addition of $O_2(g)$.

Item b: Addition of $Cl_2(g)$.

Item c: Decrease in the volume of the vessel.

Item d: Increase in the temperature of the vessel.

Posttest 4 (13 week)

Consider the following reaction in equilibrium:

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad (\Delta H > 0)$$

In order to increase the concentration of $O_2(g)$ in the vessel should we (justify each response):

Item a: Increase the pressure of the vessel.

Item b: Add a certain amount of $NO_2(g)$.

Item c: Extract a certain amount of $NO(g)$.

Item d: Increase the temperature.

Posttest 5 (13 week)

Consider the following reaction in equilibrium:

$$2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g) \qquad (\Delta H > 0)$$

Describe the effect of the following on the position of the equilibrium:

Item a: Addition of $Cl_2(g)$.

Select one of the following responses and justify

a1# On addition of $Cl_2(g)$ more products will be produced and in order to counteract the effect, the reaction would proceed from right to left.

a2* On adding $Cl_2(g)$ the system must counteract and consequently the rate of the forward reaction would increase.

a3 None of the previous.

Item b: Increase in the temperature of the vessel.

Select one of the following responses and justify

b1* As the reaction is endothermic, an increase in temperature would lead to the absorption of heat and the system must counteract, leading to an increase in the rate of the forward reaction.

b2# As the reaction is endothermic, an increase in temperature would lead to the absorption of heat, producing more products and in order to counteract the effect the reaction would proceed from right to left.

b3 None of the previous.

#'Force' response

*Correct response

RESULTS AND DISCUSSION

Posttest 1

Results obtained show the advantage of Ss in the experimental group in all four items (see Table 1). The difference, however, is significant only in Item d. In spite of the close relationship between the problems used in Teaching Experiment 1 and Posttest 1, very few Ss in the experimental group responded correctly to Item a. It is important to note that the problem in Posttest 1 deals with a situation conceptually more difficult (i.e., a change in experimental conditions) as to the one presented in Teaching Experiment 1 (approaching equilibrium). Interestingly, only 11% of the Ss in the experimental group understood that the rate of the reverse reaction cannot decrease (Item a) and yet 39% of the Ss responded correctly to Item d, that is, reverse reaction rate increases gradually. This once again shows the contradiction in student responses and perhaps a propensity to change. It is plausible to suggest that Item a represents the core belief (Lakatos', 1970, hard core) of the Ss. Some of the Ss in the experimental group reasoned along the following lines:

- "As the forward reaction rate increases, the reverse reaction rate must decrease gradually, in order to establish equilibrium once again". Apparently, the Ss are not aware of the contradiction involved in this response. One could ask: If the forward reaction rate increases and the reverse reaction rate decreases gradually, how would the two reach equilibrium once again.
- "Forward reaction rate is favored in order to consume the excess of NO, and at the same time the production of NOCl is limited". Again it is interesting to ask: How can we increase the forward reaction rate and not increase the production of NOCl.

- "Reverse reaction rate is proportional to $[NOCl]^2$. Consequently, the rate of the reverse reaction must decrease".

These three types of responses show the contradictory nature of student understanding and it is plausible to suggest that such reasoning is invoked in order to protect the hard core of student beliefs and can be considered as 'auxiliary hypotheses' within the Lakatosian framework (cf. first section of the manuscript).

Insert Table 1 about here

Posttest 2

Results obtained once again show the advantage of Ss in the experimental group (see Table 1). The same 8 Ss in the experimental group responded correctly to Items a, b, and c. Items d and e were not solved correctly by any of the Ss in the experimental and control groups.

Posttest 3

Results obtained show the advantage of Ss in the experimental group (see Table 1), specially on Items a and b. The difference, however, is significant only in Item a. It is plausible to suggest that the problem situation in Posttest 3 requires considerably less conceptual understanding as compared to the problems in posttests 1 and 2 and also the teaching experiments. It is interesting to observe that even on a fairly traditional question (Posttest 3, found in textbooks) performance of the experimental group is generally better than that of the control group.

Posttest 4

This being a delayed posttest, it can be observed that the difference in the performance of the two groups (except for Item b) is considerably less (see Table 1). Comparing the performance of the two groups on Posttests 3 and 4, it can be observed that even a small change in the problem format, affects student performance considerably. Both problems being quite similar, it was expected that a training effect could have improved performance on Posttest 4 as compared to Posttest 3.

Posttest 5

The objective of this posttest was to evaluate the teaching strategy developed in this study with respect to the utilization of a 'force' interpretation by the Ss. Niaz (1995c) has shown that Ss tend to conceptualize the rates of the forward and reverse reactions in chemical equilibrium as forces, perhaps in the same sense as used in the evolution of the concept of chemical equilibrium and student misconceptions about Newton's third law of motion. According to Lindauer (1962): "Although chemical equilibrium is no longer looked upon as a revelation of the forces which control chemical change, much of its development arose out of just such an expectation" (p. 384, emphasis added). Actually, it was in 1884 that Van't Hoff (1896) finally presented the law of mass action on the basis of reaction velocities and the dynamic nature of chemical equilibrium was recognized as a consequence of the velocities of the forward and reverse reactions being equal at equilibrium. Results obtained (see Table 1) show that Ss in the experimental group have a better understanding of the forward and reverse reactions as velocities. Nevertheless, it appears that as compared to the previous results (Niaz, 1995c) the teaching experiments in this study did not improve student understanding of the dynamic nature of chemical equilibrium. The following are some examples of the force responses given by the experimental group:

- "On increasing the concentration of the reactants, that of the products decreases, and in order to counteract this the rate of the forward reaction is favored. Now in order to counteract the increase in [Cl_2], the rate of the reverse reaction increases" (Item a). It appears that in order to respond the student has first cast the problem within his/her own framework. For example, it helps the student to invoke the force response (based on an epigrammatic version of Newton's third law, viz., for every action there is an equal and opposite reaction, cf., Brown & Clement, 1987) by hypothesizing that when the concentration of the reactants increase that of the products would decrease.
- "As the concentration of the reactants increase that of products would decrease. The relation between the concentration of the products and reactants decreases, and consequently the rate of the reverse reaction would also decrease. This leads to an increase in the rate of the forward reaction" (Item a).
- "If the concentration of the products increases, <u>logically</u> the

rate of the reverse reaction would increase" (Item b, emphasis added). Once again the student has hypothsized on his own account that the concentration of the products was also altered as an external effect.

It is plausible to suggest that as scientists build models of increaseing complexity, which lead to epistemic transitions (i.e., increase heuristic/explanatory power, cf., Lakatos, 1970, p. 137), similarly, students build a series of evolving models (progressive transitions), leading to greater conceptual understanding. In the present case there is a progressive 'problemshift' (Lakatos, 1970) between the model which represents chemical equilibrium as resulting from an equality of the chemical forces (Lindauer, 1962) and the model that represents the dynamic nature of chemical equilibrium.

CONCLUSIONS AND EDUCATIONAL IMPLICATIONS

Results obtained show that performance of the experimental group was generally better than that of the control group. Nevertheless, it is important to point out that on an item related to a core belief of the students (posttest 1, Item a) the gain of the experimental group is fairly modest. It was also observed that results of the immediate posttests (3 weeks after intervention) were better than those of the delayed posttests (8 weeks after intervention). In general student performance on traditional and familiar items generally found in textbooks (e.g., posttests 3 and

4) was better than on novel problems requiring greater conceptual understanding (e.g., posttest 1). It is concluded that even relatively short periods of appropriate experiences can facilitate student understanding of chemical equilibrium. Further research could show the advantage of extended periods of intervention.

It is suggested that the following aspects of this study can be utilized by the teachers to design better teaching strategies:

1. Looking for the core beliefs (cf. 'hard core', Lakatos, 1970) of the students in a topic can be an appropriate starting point for a teaching strategy.
2. Exploration of the relationship between core beliefs and student alternative conceptions (misconceptions) could be the next step. In order to implement this, it is essential that student misconceptions be interpreted within an epistemological perspective. According to Strike and Posner (1992): "... a misconception is not merely a mistake or a false belief. Either it must also play the kind of organizing role in cognition that paradigms play, or it must be dependent on such organizing concepts .... A misconception, thus, may become a candidate for change" (p. 153).
3. The cognitive complexity of the core belief can be broken down into a series of related and probing questions (cf. Teaching Experiments 1 and 2). This can be facilitated by identifying the core beliefs (hard core), which are more resistant to change and the soft core of student beliefs (see criteria for classification in first section)

4. Students resist changes in their core beliefs (e.g., the rate of the forward reaction increases with time) more strongly than those in other related aspects of a topic (cf. Chinn & Brewer, 1993). 'Auxiliary hypotheses' used by students to defend their core beliefs can provide clues and guidance for the construction of novel teaching strategies.

5. It is important that students' responses based on their misconceptions be considered not as wrong, but rather as models perhaps in the same sense as used by scientists to simplify the complexity of a problem.

6. In spite of the similarities between Strike and Posner (1992) model of conceptual change and our model, it is essential to point out an important difference. Strike and Posner consider students' misconceptions as similar to paradigms in the Kuhnian (Kuhn, 1970) sense, and hence their resistance to change. On the other hand, we consider students' misconceptions as alternative conceptions (theories) that compete with the present scientific theories (and at times recapitulate theories that the scientists held in the past) in the Lakatosian sense (Lakatos, 1970). This important epistemological difference is important for educators, as Kuhnian paradigms imply the incommensurability thesis, that has been the subject of considerable controversy (cf. Barker & Gholson, 1984; Friman, et al., 1993; Lakatos, 1970; Malone, 1993; Reese & Overton, 1972; Segal & Lachman, 1972). For science educators, the crux of the issue is that according to

Kuhn (1970) different paradigms are incommensurate because their core beliefs are resistant to change and that paradigms do not merge over time, rather they displace each other after periods of chaotic upheaval or scientific revolution. In a nut-shell, misconceptions interpreted as paradigms lead to situations that are not conducive to debate as Kuhn's (1970) incommensurability thesis implies that any one science can accommodate only one paradigm. A Lakatosian conceptual change teaching strategy after having identified the hard and the soft core of students' beliefs will look for 'auxiliary hypotheses' students use to protect their core beliefs and subsequently introduce/construct alternative explanations that contradict their original beliefs. On the other hand, a Kuhnian conceptual change teaching strategy would perhaps consider students' beliefs as more rigid and less conducive to change. Strike and Posner (1992), for example, accept the criticism that their model of conceptual change does not forsee explicit instructional strategies of the sort used in this study (p. 169).

7. It is plausible to suggest that results obtained in this study reflect, primarily a change/shift in the soft core of students' beliefs. This raises an important issue: In order to be accepted as valid, should teaching strategies necessarily produce changes in the hard core of students' beliefs? A recent study by Dagher (1994) provides a possible answer: "Restricting worthwhile conceptual change to the

radical type is equivalent to restricting worthwhile science to revolutionary science --- at a time when, if one accepts Kuhn's theory of scientific activity, it is during the normal and ordinary tinkering within a given paradigm that crises arise and eventual dissatisfaction ensues. The small changes in conception are worth tracking because their significance to the intellectual life of individuals is far beyond our ability to ascertain at this stage of our understanding" (p. 609). Interestingly, Lakatos (1970) has emphasized that the hard core of a program itself develops slowly by a long preliminary process of trial and error and does not emerge fully armed like, " Athene from the head of Zeus" (p. 133). This leads to a plausible conclusion: just as the hard core of students' beliefs is constructed slowly, any change perhaps will also follow a similar process.

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Table 1

Comparison of Performance of the Experimental and Control Groups on Different Posttests

Posttest	No. of students with correct response		
	Experimental Group (N=36)	Control Group (N=32)	χ^2 (Sig.)
1			
Item a	4 (11)*	-	
Item b	12 (33)	6 (19)	1.18 (ns)
Item c	7 (19)	1 (3)	2.92 (ns)
Item d	14 (39)	4 (13)	4.78 ($p < .05$)
2			
Item a	8 (22)	3 (9)	1.22 (ns)
Item b	8 (22)	3 (9)	1.22 (ns)
Item c	8 (22)	2 (6)	2.29 (ns)
Item d	-	-	
Item e	-	-	
3			
Item a	25 (69)	13 (41)	4.59 ($p < .05$)
Item b	25 (69)	14 (44)	3.58 (ns)
Item c	10 (28)	8 (25)	
Item d	12 (33)	5 (16)	1.97 (ns)
4			
Item a	6 (17)	5 (16)	
Item b	19 (53)	11 (34)	1.64 (ns)
Item c	11 (31)	8 (25)	
Item d	11 (31)	9 (28)	
5			
Item a	21 (58)	15 (47)	0.49 (ns)
Item b	16 (44)	13 (41)	

*Figures in parentheses represent percentages